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Depth of cure of resin composites: effect of incremental layering versus bulk placement and effect of curing light type

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DEPTH OF CURE OF RESIN COMPOSITES: EFFECT OF INCREMENTAL LAYERING VERSUS BULK PLACEMENT AND EFFECT OF CURING LIGHT TYPE

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A Thesis Presented to Faculty of the College of Dental Medicine of Nova Southeastern University in Partial Fulfillment of the Requirements for the Degree of

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DATE SUBMITED: May 04, 2018

I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.S. degree and for this assignment.

STUDENT SIGNATURE: ____

Najat K. Aldossarry, B.D.S.   Date

DEDICATION

My deep gratitude goes first to my parents, Mr. Khalid Aldossarry and Mrs. Sanaa Dawood, who guided me through my educational path and supported me. Thank you for believing in me, thank you for your unconditioned love and support, without your inspiration and enthusiasm none of my achievements would have happened. To my dear husband Mohanad Abumelha, without your generous help, support and encouragement I would not have accomplished my postgraduate educational journey.

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ABSTRACT

DEPTH OF CURE OF RESIN COMPOSITES: EFFECT OF INCREMENTAL LAYERING VERSUS BULK PLACEMENT AND EFFECT OF CURING LIGHT TYPE

DEGREE DATE: May 2018

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Background: The introduction of resin composite was a revolution in dentistry and it has shown a high level of success as a direct restorative material. Appropriate techniques and light curing units are essential for optimal clinical outcomes. **Objective:** To assess depth of cure of two bulk-fill composites and one nanofill resin composite, when photopolymerized with two different curing light units (CLU), placed with an incremental layering versus bulk-fill technique. **Material and methods:** Two Bulk-fill resin composites (Surefil SDR® Flow and Tetric EvoCeram®) and a conventional nanofill (Filtek™ Supreme Ultra) were used to prepare 90 cylindrical specimens. Specimens (n=5/group) were made using two placement techniques (incremental and bulk-fill). Each specimen was polymerized using one of two LCUs (Valo® LED [standard power or extra-power mode] and OptiLux 501® QTH), with irradiation times set according to the manufacturer recommendations. Vickers microhardness was evaluated starting from the top to the bottom surface of each specimen. Ten measurements were made sequentially (0.4 mm intervals). A three-way ANOVA and Tukey's post hoc test was used (significance of 0.05) to analyze the DOC data. **Results**: All resin composite groups cured with LED CLU (extra-power for 3 sec) and placed using a bulk-fill technique showed significant differences ($p<0.05$) in hardness ratio (DOC analysis). **Conclusions**: An incremental insertion technique showed a significantly higher DOC for all composite resin groups when compared to bulk insertion. Therefore, it is not recommended to use a bulk-fill technique with conventional composite. Delivering high irradiance (3200 mW/cm^2) and exposure time (3 sec) for LED CLU did not exceed the threshold value for bottom to top hardness ratio of 80% at 4 mm as claimed for Bulk-fill composites when using a bulk-fill insertion technique. Tetric EvoCeram Bulk Fill achieved a 3.2-mm DOC when LED CLU standard power was used for 10 seconds using a bulk-fill insertion technique. The best results were achieved with combinations of incremental insertion and use of a QTH curing light with extended curing time (40 sec).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

1.1 DENTAL RESIN COMPOSITE:

1.1.1 Overview:

As patients have become more aware of advances in health care, including dentistry, they have shown high expectations regarding their dental treatments, and have become more concerned of how a dental restoration should look, how it will function and for how long it will survive. The introduction of resin composite was a revolution and it has shown a high level of success as a direct restorative material[1]. There have been continuous efforts to improve the physical and mechanical properties and the operating techniques used to apply resin composite[1]. Many clinicians have shown a preference for using resin composite materials for direct applications to meet their patients' expectations. Dental composite materials were developed by Bowen in 1963 by combining dimethacrylates (epoxy resin and methacrylic acid) with silanized quartz powder[2]. At that time, only chemically-cured two-component resin-based materials were available. Since the first resin composite original Bowen formulation, many modifications have been made to improve physical and mechanical properties. In the late 1970s, light-cured, resin-based composites were introduced to the dental profession[3].

1.1.2 Composition:

Resin composites consist of three main components: resin matrix (organic part), fillers (inorganic part) and coupling agents.

a. Organic resin matrix: The primary constituents of the resin matrix are resin monomers consisting mostly of Bis-GMA (bisphenol-A- glycidyldimethacrylate).

Since Bis-GMA is highly viscous alone, it is mixed with lower viscousity dimethacrylates such as TEGDMA (triethyleneglycol dimethacrylate)[4-6].

b. Inorganic filler particles: The fillers are made of quartz, silica/silicon dioxide, silicate glass, barium, strontium and zirconia with particle sizes ranging from 0.06 to 100 µm [6]. Studies showed that filler content/volume had a significant influence on the resin composite mechanical properties. The polymerization shrinkage, the linear expansion coefficient and water absorption are reduced when the filler content is increased[5]. On the contrary, the compressive and tensile strength, the modulus of elasticity, and wear resistance are generally increased when the filler content is increased[5, 7].

a. Coupling agent: The coupling agent consists mostly of organic saline, its function manly to bond inorganic fillers and organic matrix[6]. Also, it provides hydrolytic stability by preventing the penetration of water along filler resin interface[5].

In addition to those three main components an activator- initiator system is also required to initiate the polymerization process.

1.1.3 Classification:

Composites can be classified based on the size, amount, and composition of the inorganic filler or by their handling characteristics, for example, as flowable or condensable composites. In fact, the most popular classification is the Lutz & Philips classification, which is based on filler size; macro-filler composites (particles from 0.1 to 100 µ), micro-filler composites (0.04 µ particles) and hybrid-composites (fillers of different sizes)[6]. However, this classification does not do justice to today's composites, since most of the composite materials are nanocomposites, nano-filled composites, nano-filled hybrid composites or micro-hybrid composites.

1.1.3.a Nano-RBCs (Nano-"Resin-based Composites"):

"Nanotechnology" refers to the science of producing material particles size less than 100 nanometers by using chemical and physical processes[8]. Introducing nanotechnology to the field of restorative dentistry has resulted in the development of resin composites with improved physical, mechanical, esthetic and optical properties. These nanocomposites are resin composites, where the basic organic matrix has been reinforced with nanofillers. Nanocomposites are classified into two types:

Nanohybrid resin composite: Contain milled glass fillers along with nanoparticles in the size range of 40-50nm[8].

Nanofill resin composite: Formed by a combination of: (a) Nanomers, which are nanosized mono-dispersed, non-aggregated silica filler particles in the size range of 20-75 nm and (b) Nanoclusters, which are agglomerations of a combination of zirconia-silica and silica nanomeric particles[8, 9].

Previous studies have reported that Nano-RBCs show high translucency and high polishability similar to microfill-resin composites, while still providing physical properties and wear resistance equivalent to hybrid-resin composites[9]. Due to these superior properties, dentists are using Nano-RBCs in anterior and posterior teeth by incremental placement technique, with approximately 2 mm thick increments. The incremental placement technique facilitates an esthetically-pleasing material manipulation, by creating multi-shade restorations, excellent adaptation, and helps managing the shrinkage stress, reducing the C-factor, which is defined as the ratio of the bonded surface area to un-bonded surface area of a restoration[10, 11]. Nevertheless, the incremental placement technique is considered a very sensitive technique. Potential consequences include the possibility of contamination and void formation between increments. Additionally, the incremental placement technique is known as a time consuming technique, as it requires significant time to place, adapt and cure each increment[12].

1.1.3.b Bulk-fill RBCs:

Bulk-fill resin composite is a relatively new category of posterior resin composite that has improved depth of cure and reduced shrinkage characteristics. With similar composition of a conventional resin composite, modifications have been made by increasing the filler particle size or decreasing the filler content, or by adding photo-initiators to increase the depth of cure[13-15]. A big advantage of this material is the possibility to achieve a depth of cure up to 4-5 mm thickness as a single layer to overcome some of the limitations of the incremental placement technique[13]. Bulk-fill restorative materials can be categorized into:

a. Low-viscosity (flowable) light-cured bulk-fill RBC materials: These cannot be sculpted and require an additional 2 mm superficial final layer (capping layer) of conventional resin composite in order to created morphology and match the tooth shade. Nevertheless, these could still be a preferred choice for dentists for their ease of use, including adaptation[15, 16].

b. High viscosity (non-flowable), light-cured bulk-fill RBC materials: These can be sculpted without a capping layer[1, 15]. High viscosity light-cured (non-flowable) RBCs are reported to have higher wear resistance than the low-viscosity (flowable) light-cured composites. This explains the need for a final conventional layer of RBC (capping layer) to enhance the wear resistance and hardness[15, 16].

c. Dual cure bulk-fill RBC: These are suitable for cavities at any depth since they combine chemical and light-cure properties. The surface of the restoration can be light-cured for finishing and polishing, while the full depth (bulk) of the restoration will be chemically-cured within minutes[15].

Bulk-fill RBC materials provide good mechanical properties, acceptable aesthetic results and less time-consuming placement techniques. Multiple clinical studies concluded bulk-fill base composites are a suitable alternative to amalgam or conventional RBC[15, 17-19]. Additionally, in a comparison between a bulk-fill material and a conventional RBC, it was reported that a similar volumetric shrinkage was measured for both [15, 20]. Also, a study has reported that pulpotomized primary molars restored using bulk-fill base RBCs were as successful as those restored using stainless steel crowns[15, 21]. However, bulk-fill RBC restorative materials have limited clinical research studies to support their use.

In conclusion, clinicians must be aware of the advantages and limitations of each material chosen for a specific clinical case. Beside the restorative material performance, dental restoration success is based on additional essential requirements, such as patient oral hygiene, adhesive system and clinician knowledge (skills of carefully and correctly handling the materials)[5, 22].

1.2 POLYMERIZATION:

The polymerization of the material is determined by the degree of conversion of monomers into polymers, indicating the number of methacrylate groups that have reacted with each other during the conversion process[6]. As a matter of fact, the polymerization process is influenced by several factors.

1.2.1 Factors that influence the degree of conversion:

a. Shade of resin composite: The lighter resin composite shades show superior hardness when compared to darker shades[23]. In addition to resin composite shade, the resin composite translucency can affect the polymerization process by affecting light transmission through the material[24].

b. Type of filler: Both filler content and size influence light dispersion. The maximum light scattering happens when the filler particles are small (0.1 μm to 1.0 μm), because these particle sizes correspond to the wavelength range of the photoinitiator[25]. Microfilled composites with smaller or larger particles scatter more light than microhybrids[25].

c. Light source quality and type of photo-initiator: Each light-curing unit has its own wavelength specifications, advantages, limitations, and curing efficiency. The wavelength is an important determining factor in the performance of a curing lamp. Most Halogen and LED curing units have wavelengths between 400 and 510 nm. It must be taken into account that the wavelength should match the absorption spectrum or absorption peak of the photo-initiator in the resin composite[25]. For example, the camphoroquinone absorption curve covers a range from 360 to 520 nm, with a peak at 465 nm, while for Lucirin TPO, absorption is from 390 to 410 nm, for PPD it is from 390 to 460 nm, and for Ivocerin is from 390 to 445 nm. Moreover, the curing light intensity depends on the light guide, filters and the condition of the bulb. In fact, the light intensity decreases when the distance from the curing risen composite is increased[26]. Usually, light intensity and curing effectiveness of any light-curing unit should be maintained, because it reduces with time.

d. Distance between light and resin composite: The tip of the curing light must be positioned perpendicular and as close as possible to the resin composite restoration surface[27, 28]. It has been found that increasing the distance from the light-cure tip to the RBC restoration surface, results in light intensity being decreased by 10% for every 1 mm the light source is moved further away[29].

e. Thickness of the resin composite increment: The gold standard layer thickness for resin composite is 1.5-2 mm for each increment, whereas bulk-fill composite materials are claimed to be curable at increment thickness of up to 4-5 mm.

f. Curing time: The exposure time recommended by resin composite manufactures may be different from those recommended by the curing light manufactures[30]. To determine the exact time needed for curing a resin composite, curing time can be estimated using the formula:

$$\text{Resulting curing time} = \frac{\text{Required energy dose}}{\text{Light intensity}}$$

Moreover, increasing the light intensity reduces the required exposure time at a given depth and also increases the rate and degree of cure[25].

Photopolymerization is critical for the success of a resin composite restoration. Inappropriate photopolymerization can result in uncured resin composite, which could lead to clinical problems such as: poor physical/mechanical properties, post-operative sensitivity, pulp irritation, microleakage, recurrent caries and cusp deflection when the “C” factor is high[31, 32].

1.3 CURING LIGHTS:

1.3.1 Overview:

Numerous curing light systems, including high intensity quartz tungsten halogen (QTH), light emitting diode (LED) and plasma arc, are available on the market, and they have been used by clinicians in order to obtain good clinical outcomes. In 1978, the first light used in curing resin composite was the ultra-violet light (UVL), which had limited achievement of depth of cure[3]. However, the UVL curing unit is no longer available, due to the safety concerns, whereas QTH units have been developed and dominated the market for most of the 1980s and 1990s[33]. At the beginning of the 21st century, the LED light has become the gold standard of curing dental resin composite materials[34]. Studies have reported that the mechanical properties of LED cured dental composites clarify that the LED CLUs were convenient for photopolymerization of dental resin composites[34]. However, the degree of polymerization achieved by LED units is considered to be similar to QTH units[35]. It can be surmised that better understanding of light intensity, emission spectrum, and light delivered from the curing unit, to match the absorption spectrum or absorption peak of the photoiniator in the resin composite, is critical to improve the ability to clinically deliver a successful restoration.

1.3.2 Factors Associated with light curing unit:

1. Light intensity.
2. Exposure Time.
3. Distance of curing tip from RBC surface.
4. Angulation of the light tip.
5. Size of light curing tip (Tip Geometry): Light guides are available in diameters of 3

mm, 8 mm, 10 mm, 11 mm, 13 mm, and 14 mm. Most light curing units have standardized light tip diameter (11 mm) that emits energy in a more diffuse manner, whereas light-curing units with a smaller tip (3mm; turboguide) have more concentrated energy emission, and increase the output of light energy, but also increase the temperature of both the tooth structure and the resin restoration[25].

6. Type of Curing unit:

a. Quartz-tungsten-halogen (QTH):

In the late 1970's, the first visible light (QTH) was used to photopolymerize resin composite. The (QTH) bulb contains a tungsten filament enclosed in a clear, crystalline quartz casing, filled with a halogen-based gas[25, 36]. It irradiates both UV and white light, that must be filtered to remove heat, and transmit light only in the violet-blue region of the spectrum that matches the photoabsorption range of a camphorquinone photoinitiator[36]. QTH curing lights emit a broad emission spectrum, with working wavelengths of 400 nm to 500 nm, and output (intensity) ranging from 400 mW/ cm^2 to 800 mW/cm^2. Despite the fact that QTH has the ability to activate most of the photoinitiator due to its broad emission spectrum, it still has drawbacks, such as the long exposure time needed for photo-polymerizing a 2 mm layer (40 to 60 seconds)[36].

b. Light Emitting Diode (Blue LED):

First-Generation Light-Emitting Diode Lights: The blue wavelength output of these early (LED) units was in the range of maximum absorption of camphorquinone photoinitiator, and was comparable with the QTH source of that time[36, 37]. Although these initial units delivered a lower energy power output with extended exposure time[36, 37].

Second-Generation Light-Emitting Diode Lights: The second generation of LED CLUs were more powerful than the “first-generation” LED CLUs, with recommended exposure time less than the exposure time recommended from QTH lights. However, neither the first- nor the second- generation LED CLUs deliver a wavelength below 420 nm[37]. Both first and second generation of LED CLUs can cure camphorquinone photoinitiator only, but some other photoinitiator, such as Lucirin TPO, needs a broader spectrum to be cured.

Third-Generation Light-Emitting Diode Lights: Designing this generation of LED CLUs, with broad light spectrum emission, was a way of solving the drawback of earlier LED CLUs. This generation can also be described as Multiwave, Multipeak, and Polywave dental curing lights. In fact, these lights emit a combination of violet and blue light, with a wavelength range of 380 to 500 nm (broad emission spectrum). These lights activate camphorquinone photoinitiator, in addition to the alternative photoinitiators such as TPO and Ivocerin®, to produce higher color value resin composite, and to help increase depth of cure, especially for some bulk-fil resin composite[36]. Overall, the emission spectrum third generation LED LCUs is comparable to the effective range of halogen lights[37].

1.4 DEPTH OF CURE:

1.4.1 Overview:

Depth of cure and microhardness are considered to be essential physical properties of composite resin materials. In order to assess the depth of cure, multiple methods have been used, such as the ISO 4049 standard, optical microscopy, degree of conversion, and measuring the hardness of the top and bottom of specimen surfaces[38].

1.4.2 ISO standard for dental composites 4049 method:

In the year of 1988, the maximum recommended increment thickness of resin composites was 2 mm thickness as single layer. This thickness was defined by the International Organization for Standardization ISO in the second edition of ISO 4049[39]. The ISO standard for dental composites (4049), was developed using one of the first visible light-curing microfilled resin composites (Durafill, Kulzer & Co GmbH, Bad Homburg, West Germany)[39]. For this method, a cylindrical specimen prepared by using a stainless steel mold with suggested dimensions of 6 mm long and 4 mm in diameter, unless the manufacturer claims a depth of cure more than 3 mm, then the length should be at least 2 mm longer than twice the claimed depth of cure. This method involves removal of unset material, scraped immediately after curing light irradiation, from the bottom of the specimen, and measuring the length of the remaining set specimen, which is then divided by two[38-40]. However, the bulk-fill resin composite material has modifications in the composition (e.g. the initiator and the filler size), allowing a greater curing depth, up to 4 mm as a single layer, which eventually challenged the accuracy of ISO 4049 in defining acceptable maximum composite increment thickness. A study showed that the ISO 4049 test method, used to evaluate bulk-fill materials, overestimated DC compared to depth of cure determined by Vickers hardness profiles[39].

1.4.3 Vickers/Knoop hardness profile measurement:

"Hardness profile" is one of the indirect methods used to determine depth of cure[41]. Vickers/Knoop hardness measurements are methods used specimen after curing to evaluate depth of cure, and allow for post-irradiation polymerization (if it occurs).

The Knoop hardness test utilizes a diamond elongated pyramid shaped indenter that is ground to an elongated pyramidal form, and produces a diamond shaped indentation with a depth of indentation of about 1/30 of the indentation's length. The Vickers hardness test utilizes a diamond pyramid shaped indenter that is ground in the form of a squared pyramid with an angle of 136° between faces, and the depth of indentation is about 1/7 of the resulting impression's diagonal length.

For hardness profiling, test specimens are usually prepared in cylindrical molds. Before taking hardness measurements, the cured specimens are stored in distilled water for 24 hours in order to allow for any post-irradiation polymerization. The cylinders are cut vertically into two pieces, where cut surfaces are then polished. Hardness is determined at specific intervals from the top (where the light source interacted with the specimen) to the bottom (where uncured material was scraped away). An acceptable curing depth is achieved, if the bottom hardness corresponds to at least 80% of the surface hardness[42, 43]. The mean Vickers hardness and hardness ratio of the specimens can be calculated using the formula:

$$\text{Hardness ratio } = \frac{\text{VK of bottom surface}}{\text{VK of top surface}}$$

1.5 Purpose of the study:

The purpose of this in vitro study was to assess the post-cure depth of cure (DOC) of bulk-fill resin composite compared to nanofilled resin composite, when photopolymerized with two different curing lights, and when placed in incremental layering versus a bulk-fill technique.

1.6 Research questions:

- What is the most effective technique for placement of resin composite in posterior teeth, incremental layering or bulk-fill?
- Is there a difference in the depth of cure when different types of composite or different types of light curing units are used?

In this study, the effect of curing light on the depth of cure of a resin composite was evaluated. The results obtained from this study can be utilized to determine guidelines for the clinician in order to obtain good clinical outcomes while using resin composite as a direct restorative material.

1.7 Specific Aims and Hypothesis:

1.7.1 Specific Aims:

- To determine the depth of cure of two bulk-fill resin composites (condensable and flowable) compared to a conventional nanofilled resin composite, placed in two layers of 2 mm using an incremental layering method, or one 4 mm increment using a bulk-fill technique.
- To evaluate the effect of two different light curing units (LED and QTH) on the depth of cure of two bulk-fill resin composites (condensable and flowable) compared to a conventional nanofilled resin composite, placed in two layers of 2 mm using an incremental layering method, or one 4 mm increment using a bulk-fill technique.

1.7.2 Null Hypotheses:

- The first null hypothesis tested is that there is no difference in the depth of cure of bulk-fill resin composites (condensable and flowable) when compared to a conventional nanofilled resin composite placed in two layers of 2 mm using an incremental layering method, or one 4 mm increment using a bulk-fill technique, when a specific curing light is used (LED or QTH).
- The second null hypothesis tested is that there is no difference in the depth cure of bulk-fill resin composites (condensable and flowable) when compared to a conventional nanofilled resin composite placed in two layers of 2 mm using an incremental layering method, or one 4 mm increment using a bulk-fill technique, when using two different light curing units (LED and QTH).

1.8 Location of the study:

The design, preparation and data collection of the study took place at:

Bioscience Research Center, Room 7356
Nova Southeastern University
Health Professions Division
College of Dental Medicine
3200 South University Drive
Fort Lauderdale,
Florida 33328-2018

CHAPTER 2

Materials and Methods

2.1 Experimental Design:

2.1.1 Pilot study:

A pilot study was conducted using one sample for each research group. All equipment was calibrated and techniques were reviewed (from equipment literature).

2.1.2 Sample size calculation:

In order to determine the sample size, data from Alrahlah et al[44], AlQahtani et al[45], and Price et al[46] were used as references. These studies focused on evaluation of the polymerization behavior and depth of cure of different types of light-cured resin composites used for restoration of posterior teeth. Vickers microhardness was used as an indirect evaluation for the extent of polymerization, by measuring the depth of cure. Based on sample size calculations, given a power of 80%, a delta of 2.63, an alpha of 0.05 and an additional 5% more in the sample number to account for potential loss of specimens, it was determined that the number of specimens needed for each study group, to ensure statistical relevance, was n = 5 per group (with 10 measurements per specimen).

2.1.3 Specimen Preparation:

Similar to ISO 4049 depth of cure scrape test guidelines, a metal cylindrical mold (Figure 1) containing a slot of dimensions 4 mm wide x 8 mm long was used in the fabrication of specimens. A polyester matrix strip (Mylar strip) was placed on the bottom of the mold.

The mold was then overfilled with one of the three resin composites (Table 1), and a second Mylar strip was placed on the top of the filled mold (Figure 2). A glass slab was subsequently pressed against the upper Mylar strip to extrude excess resin composite and to form a flat top surface (Figure 3). The mold was kept stable and held together in a clamp. Then, resin composite was irradiated through the Mylar strip from the top surface by using one of the two curing-light units (Table 2), keeping the tip of the curing-light unit in contact with material to ensure a constant distance from the specimen (Figure 4). Irradiation time was determined for each combination of material and curing light according to the manufacture recommendations (Table 3). The curing light units were maintained at full charge before use, and radiometer systems (Bluephase® Meter II, Ivoclar Vivadent, Austria) and (Demetron Model 100 Curing Radiometer, Demetron Research Corp, Danbury, CT) were used to verify the light intensity (mW/cm^2) at each use of the curing-light units (Figure 5). A notch was done at the bottom of the specimen in order to differentiate between the top and bottom surfaces. For the incremental layering of resin composite placement, the mold was overfilled with 4 mm of composite as a base and cured to allow better placement via the layering technique. An increment of 2 mm was then inserted and light-cured. Next, a second 2 mm increment was inserted and light-cured (Figure 6). For the bulk-fill insertion placement, 4 mm of resin composite was placed and light-cured. After polymerization, each specimen was removed from the mold and uncured material was scraped away (Figure 7). Then, the specimens were placed in a black container and stored in distilled water for 24 hours at 37°C (Figure 8). After that, specimens were mounted and placed in a sample leveling press (MetLab Corporation, Niagara Falls, NY, USA) in order to level the samples (Figure 9), then they were ground using a sequence of #320, #400, #600, #800 #1200 wet grit silicon carbide papers (MetaServ® 2000, Buehler ITW, Lake Bluff, IL, USA) (Figure 10,11). The grinding and polishing procedures were performed on one side of each specimen to obtain a polished surface to make indentations more visible in the microscope (Figure 12). A hardness tester (BUEHLER, Lake Bluff, Illinois USA) was calibrated, and then a Vickers diamond indenter was applied ten times to each specimen as a function of depth of material at 0.4 mm intervals, with a 200 g load to the top and the bottom of each sample surface with a dwell time of 15 seconds (Figure 13,14).

2.2 Experimental Groups:

Study groups can be found on Table 1. Table 2 and Table 3 present all materials and devices that were used in the study.

Specimens were divided into eighteen groups according to type of resin composite: Bulk-fill flowable (Surefil SDR® Flow [SDR]), Bulk-fill non-flowable (Tetric EvoCeram® [TEB]), and a conventional nano-filled (Filtek™ Supreme Ultra [FS]) and curing light units (Valo® LED [standard power or extra power mode] or OptiLux 501® QTH) and two placement techniques (2 layers of 2 mm incremental layering or 4 mm bulk-fill). Each group had 5 specimens (*n=5*), and each resin composite specimen was assigned to one of two curing light units and placement techniques. The description of each group was as follow:

Group 1: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 2-2 mm increments cured by Valo® LED (standard power).

Group 2: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 2-2 mm increments cured by Valo® LED (extra power).

Group 3: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 2-2 mm increments cured by OptiLux 501® QTH.

Group 4: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 4 mm in-bulk cured by Valo® LED (standard power).

Group 5: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 4 mm in-bulk cured by Valo® LED (extra power).

Group 6: Bulk-fill flowable (Surefil SDR® Flow [SDR]) placed 4 mm in-bulk cured by OptiLux 501® QTH.

Group 7: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 2-2 mm increments cured by Valo® LED (standard power).

Group 8: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 2-2 mm increments cured by Valo® LED (extra power).

Group 9: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 2-2 mm increments cured by OptiLux 501® QTH.

Group 10: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 4 mm in-bulk cured by Valo® LED (standard power).

Group 11: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 4 mm in-bulk cured by Valo® LED (extra power).

Group 12: Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) placed 4 mm in-bulk cured by OptiLux 501® QTH.

Group 13: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 2-2 mm increments cured by Valo® LED (standard power).

Group 14: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 2-2 mm increments cured by Valo® LED (extra power).

Group 15: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 2-2 mm increments cured by OptiLux 501® QTH.

Group 16: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 4 mm in-bulk cured by Valo® LED (standard power).

Group 17: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 4 mm in-bulk cured by Valo® LED (extra power).

Group 18: Nano-composite (Filtek™ Supreme Ultra [FS]) placed 4 mm in-bulk cured by OptiLux 501® QTH.

2.3 Surface Vickers Microhardness profile measurement:

The Depth of cure and microhardness of the resin composites were measured using microhardness instrument with a Vickers diamond indenter (BUEHLER, Lake Bluff, Illinois, USA), Figure1. The measuring indenter, the Vickers pyramid, was pressed into the resin composite specimen using a load of 200 g for 15 seconds. Ten Vickers Hardness (VK) readings were recorded for each sample surface (top and bottom); and the measurements were made in a sequential pattern (0.4 mm intervals), starting with the top surface at the center of all specimens. The mean Vickers hardness and hardness ratio of the specimens was calculated using the formula:

$$\text{Hardness ratio} = \frac{\text{VK of bottom surface}}{\text{VK of top surface}}$$

2.4 External validity:

The results obtained from this study affect the clinical decision of selection of curing light system, type of composite material and the technique of applying the composite, which will be applicable to specific dental procedures. However, this is a limited experimental study that has low validity. Additional clinical studies would be needed to validate these findings for application to actual patients.

2.5 Instrumentation:

In this study, the irradiation time was chosen based on manufacturer's instructions, while distance was standardized. The color of resin composite shade (A2) was the same for all groups regardless of composite material type. One operator did all experimental procedures and specimen preparation steps.

Dependent variables: Depth of cure (Vickers Microhardness number).

Independent variables: Type of composite resin, curing light unit and fill technique.

2.6 Data and Statistical Analysis:

Descriptive statistics, including the mean for microhardness by the independent variables light cure, composite, and depth were calculated. To test the hypothesis, a three-way ANOVA with interaction (3 x 3 x 2 factorial design) was used. The main effects were resin composite type (Bulk-fill flowable - Surefil SDR® Flow [SDR], Bulk-fill non-flowable - Tetric EvoCeram® [TEB], and a nano-filled - Filtek™ Supreme Ultra [FS]), curing light unit (Valo® LED [standard intensity or extra power] or OptiLux 501® QTH) and two placement techniques (2 layers of 2 mm incremental layering or 4 mm bulk-fill).

Tukey's Post-hoc tests were conducted using a Holm adjustment. RStudio and R 3.2.2 was used for all statistical analysis, and significance was accepted at $p < 0.05$.

Table 1: Materials Used in Experimental Evaluations

	Surefil SDR® (SDR) Dentsply	Tetric EvoCeram® Bulk-fill (TEB)	Filtek™ Supreme Ultra (FS)
Type	Bulk-fill flowable	Bulk-fill non-flowable	Nano-composite
Shade	A2	"A" range (A2-A3)	A2
Manufacturer	Dentsply Caulk, Milford, DE, USA	Ivoclar Vivadent AG, Schaan, Liechtenstein	3M ESPE, St Paul, MN, USA
Matrix System	Modified UDMA, EBPDMA, TEGDMA	Dimethacrylate co-monomers	Bis-PMA, DUDMA, Bis-GMA, TEGDMA
Filler System	Baruim aluminofluoride borosilicate glass	Ba-Glass, YbF_3, mixoxide, PPF	Zirconia/silica
Filler Load (wt% / vol%)	68 / 45	80 wt%	78.5 / 63.3
Recommendation Thickness	4 mm bulk-fill with capping layer	4 mm bulk-fill without capping layer	2 mm incremental filling

*Abbreviations: Bis-GMA, bisphenol-A diglycidyl ether dimethacrylate; Bis-MEPP, 2,2-Bis (4-methacryloxypolyethoxyphenyl) propane; DUDMA, diurethane dimethacrylate; EBPDMA, ethoxylated bisphenol-A dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate. Prepolymer includes monomer, glass filler and ytterbium fluoride. Note: Material information as supplied by manufacturer.

Table 2: Curing Light Units Used in Experimental Evaluations

	Light source	Manufacturer	Wave Length	Light Intensity (+/- 10%)
Valo®	Light emitting diode (LED)	Ultradent	395–480nm	Standard:1000 mW/cm^2 Extra power: 3200 mW/cm^2
OptiLux 501®	Quartz-tungsten-halogen (QTH)	Kerr	400-505nm	740mW/cm^2

Table 3: Resin Composite Curing Times (Per Manufacturer Recommendations)

	Light intensity	Cure time: 2 mm	Cure time: 4 mm
Surefil SDR® (SDR) Dentsply	Halogen 550-1000 mW/cm^2	20 sec	40 sec
	LED 1000-2000 mW/cm^2	10 sec	25 sec
	LED 3200 mW/cm^2	3 sec	3 sec
Tetric EvoCeram® Bulk-fill (TEB)	Halogen 550-1000 mW/cm^2	40 sec	40 sec
	LED 1000-2000 mW/cm^2	10 sec	10 sec
	LED 3200 mW/cm^2	3 sec	3 sec
Filtek™ Supreme Ultra (FS)	Halogen 550-1000 mW/cm^2	40 sec	40 sec
	LED 1000-2000 mW/cm^2	10 sec	10 sec
	LED 3200 mW/cm^2	3 sec	3 sec

Figure 1: Metal mold used for specimen fabrication.

Figure 2: Placement of resin composite into mold.

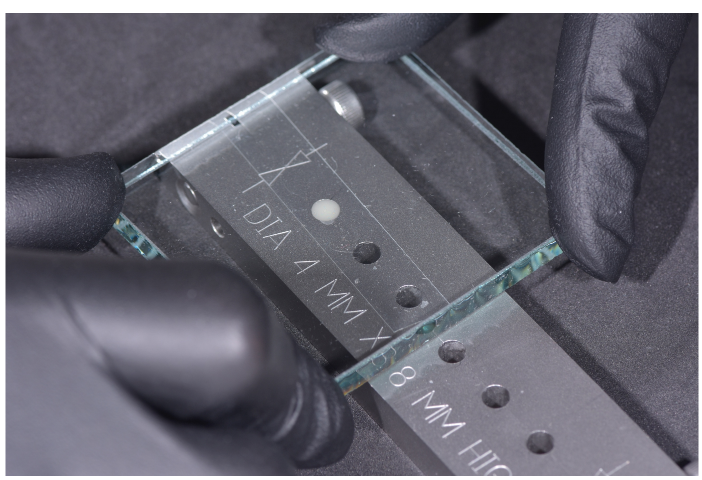

Figure 3: A glass-lab slide was used to insure a flat surface.

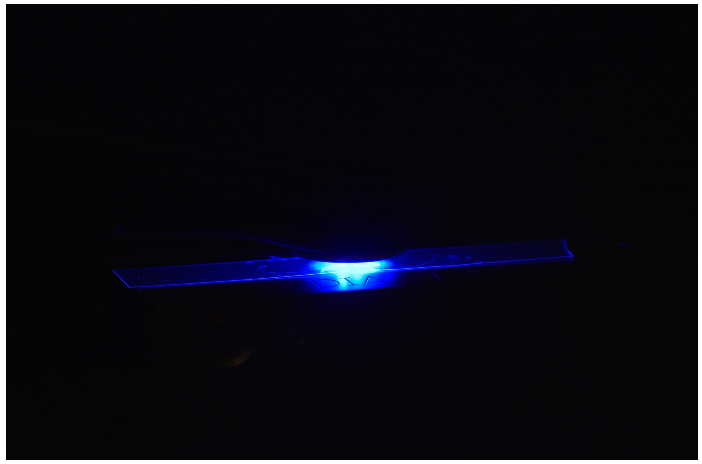

Figure 4: Each resin composite specimen was cured through a Mylar strip, to eliminate any possible oxygen inhibition of the polymerization reaction.

Figure 5: Dental radiometer systems (Demetron Model 100 Curing Radiometer (Demetron Research Corp, Danbury, CT)) and (Bluephase® Meter II, Ivoclar Vivadent, Austria) used to record curing light intensities.

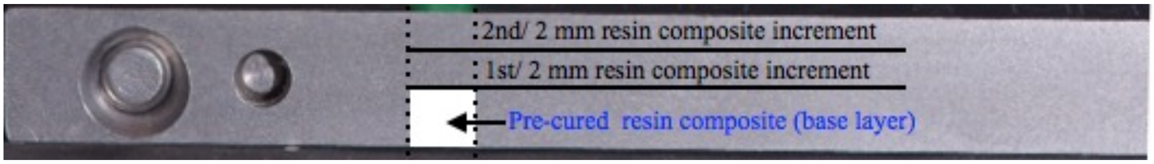

Figure 6: Mold prepared for incremental layering of resin composite placement. 4 mm of pre-cured composite was used as a base to insure that all experimental specimens had a depth of 4 mm.

Figure 7: After light curing, uncured resin composite was scraped away, so that only polymerized material was evaluated further.

Figure 8: Prior to surface modification for microhardness evaluation, all specimens were placed in a black, opaque container and stored in distilled, de-ionized water for 24 hours at 37°C.

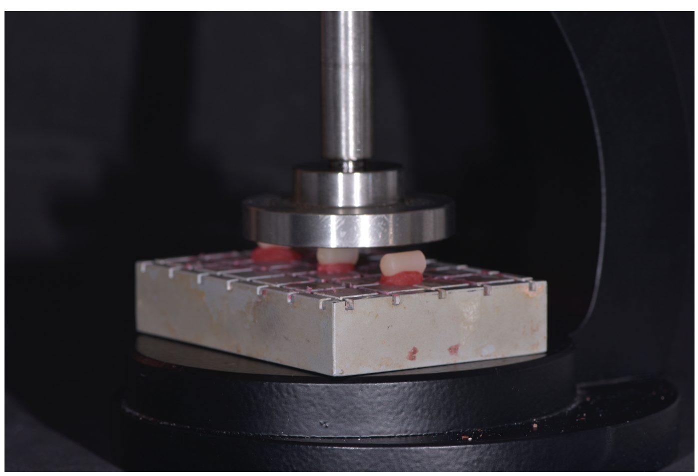

Figure 9: Samples were mounted for grinding and polishing, and leveled using a sample leveling press device.

Figure 10: MetaServ® 2000 (Buehler ITW, Lake Bluff, IL, USA) polishing device used to obtain flat surfaces for microhardness evaluation.

Figure 11: All specimens were ground and polished using a standard protocol to obtain a flat polished surface for microhardness evaluation.

Figure 12: Examples of resin composite specimens after grinding and polishing.

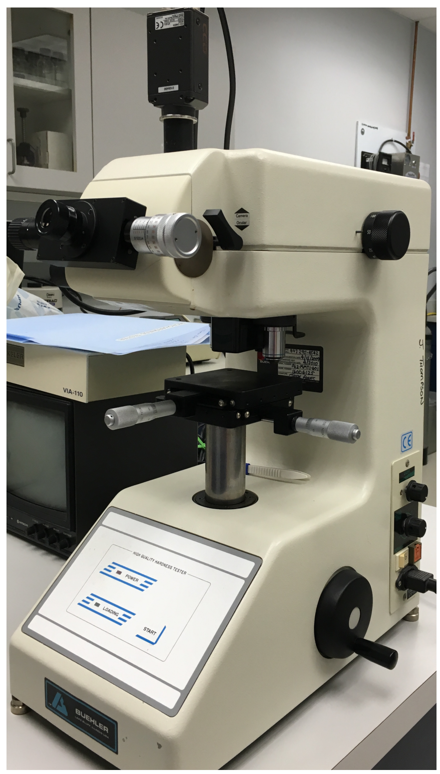

Figure 13: Microhardness Tester (BUEHLER, Lake Bluff, Illinois USA) used for surface evaluation of specimens.

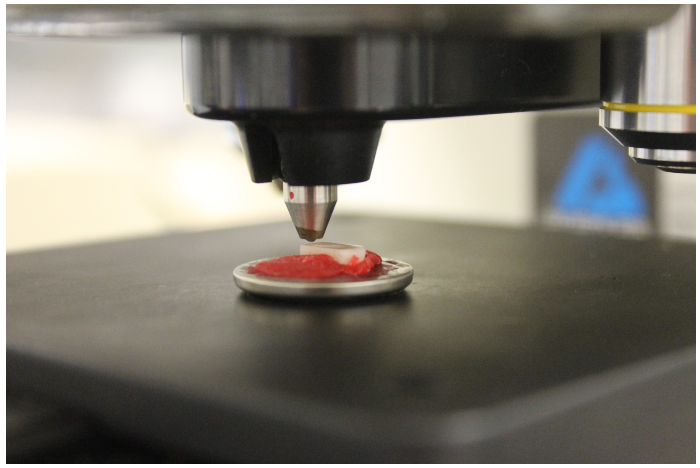

Figure 14: A Vickers diamond indenter (BUEHLER, Lake Bluff, Illinois USA) was used to evaluate microhardness.

CHAPTER 3

Results

Means and standard deviations were calculated for all continuous measures. To compare differences between the composites, three mixed, general linear models were created. The fixed factors were curing technique and curing light used, and the interaction of technique by light. The random effect was microhardness measurement. Post-hoc tests were conducted using a Holm adjustment. RStudio and R 3.2.2 (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria) were used for all statistical analysis, and significance was accepted at $p < 0.05$. Results of microhardness testing are presented in Tables 4 and 5.

Table 6 and Figure 15 show the comparison of Depth of cure (Microhardness ratio) measurements for Bulk-fill flowable (Surefil SDR® Flow [SDR]) composite resins measured at different placement (2-2 and 4 mm) using different curing lights (Valo® LED [standard power or extra power mode] or OptiLux 501® QTH): **T**here was a significant difference in the measurement of Vickers Microhardness Ratio by group F[5,24) = 33.26, p < 0.001, eta-squared = 87%]. Meaning 87% of the variability in Vickers Microhardness *Ratio* was accounted for by the differences in groups.

Table 7 and Figure 16 show the comparison of Depth of cure (microhardness ratio) measurements for Bulk-fill non-flowable (Tetric EvoCeram® [TEB]) composite resins measured at different placement (2-2 and 4 mm) using different curing lights (Valo® LED [standard power or extra power mode] or OptiLux 501® QTH): There was a significant difference in the measurement of Vickers Microhardness Ratio by group F[5,24) = 17.09, p < 0.001, eta-squared = 78%]. Meaning 78% of the variability in *Vicker's*

Microhardness Ratio was accounted for by the differences in groups.

Table 8 and Figure 17 show the comparison of Depth of cure (microhardness ratio) measurements for Nano-composite (Filtek™ Supreme Ultra [FS]) composite resins measured at different placement (2-2 and 4 mm) using different curing lights (Valo® LED [standard power or extra power mode] or OptiLux 501® QTH): There was a significant difference in the measurement of Vickers Microhardness Ratio by group $F[5,24) = 112.3$, $p < 0.001$, eta-squared = 96%]. Meaning 96% of the variability in Vickers Microhardness Ratio was accounted for by the differences in groups.

All recorded experimental data is shown in Appendices A, B, and C.

Table 4: The mean, standard deviation, minimum and maximum of VHN (surface microhardness) for each experimental group (Descriptive Statistics)

Group	N	Mean	SD	Min	Max
G1:SDR® \r\nL1 - 2-2mm	50	43.75	1.97	40.50	47.50
G2:SDR® \r\nL2 - 2-2mm	50	45.91	1.58	42.60	49.20
G3: SDR®\r\nL3- 2-2mm	50	43.83	1.77	40.90	47.40
G4:SDR® \r\nL1 - 4mm	50	45.73	2.73	42.10	57.10
G5 :SDR®\r\nL2 - 4mm	50	43.91	7.78	31.40	63.90
G6 :SDR®\r\nL3 - 4mm	50	43.05	2.52	34.10	47.80
G7:TEB®\r\nL1 - 2-2mm	50	70.92	3.95	62.90	78.90
G8:TEB®\r\nL2 - 2-2mm	50	70.31	3.37	62.10	77.20
G9:TEB®\r\nL3 -2-2mm	50	73.94	2.40	67.00	77.10
G10:TEB®\r\nL1 - 4mm	50	69.16	11.68	55.00	98.70
G11:TEB®\r\nL2 - 4mm	50	62.86	7.33	49.90	77.30
G12:TEB®\r\nL3 -4mm	50	67.56	2.50	63.50	75.30
G13:FS™ \r\nL1 - 2-2mm	50	91.88	5.29	70.50	99.30
G14:FS™ \r\nL2 - 2-2mm	50	97.03	3.01	89.70	103.50
G15:FS™\r\nL3 2-2mm	50	96.76	1.46	93.10	99.80
G16:FS™ \r\nL1 - 4mm	50	84.46	15.83	40.70	98.90
G17:FS™ \r\nL2 - 4mm	50	70.34	23.80	18.30	94.80
G18:FS™ \r\nL3 - 4mm	50	86.29	13.60	49.10	99.80

Table 5: The mean, standard deviation, minimum and maximum of microhardness ratio for each experimental group (Descriptive Statistics). Groups marked with * did not meet the criteria set by Watts (bottom surface of cured resin composite should be at least 80%) of the surface hardness. Anything below 80% is considered under-cured material, and not clinically acceptable.

Group	N	Mean	SD	Min	Max
G1:SDR® \r\nL1 - 2-2mm	50	92.50	2.48	89.59	95.51
G2:SDR® \r\nL2 - 2-2mm	50	94.98	2.17	92.68	97.73
G3: SDR®\r\nL3- 2-2mm	50	96.22	4.62	90.69	103.35
G4:SDR® \r\nL1 - 4mm	50	90.02	4.79	83.17	96.04
*G5 :SDR®\r\nL2 - 4mm	50	68.47	4.70	61.93	72.60
G6 :SDR®\r\nL3 - 4mm	50	92.71	4.43	87.56	97.21
G7:TEB®\r\nL1 - 2-2mm	50	86.01	4.19	82.11	92.01
G8:TEB®\r\nL2 - 2-2mm	50	87.64	4.38	82.80	93.19
G9:TEB®\r\nL3 -2-2mm	50	90.10	1.95	87.94	91.96
*G10: TEB®\ \r\nL1 - 4mm	50	74.35	6.72	65.87	83.18
*G11:TEB®\r\nL2 - 4mm	50	71.07	3.70	65.40	74.30
G12:TEB®\r\nL3 - 4mm	50	91.81	5.66	85.20	100.58
G13:FS™\r\nL1 -2-2mm	50	87.80	6.71	77.90	94.01
G14:FS™ \r\nL2 - 2-2mm	50	90.90	1.87	88.14	92.95
G15:FS™ \r\nL3 - 2-2mm	50	95.92	1.49	94.14	98.04
*G16:FS™\r\nL1 4mm	50	52.11	10.80	41.49	68.88
*G17:FS™ \r\nL2 - 4mm	50	24.57	5.07	19.81	31.48
*G18:FS™ \r\nL3 - 4mm	50	55.36	4.49	49.50	61.77

Table 6: Pairwise Comparisons - Groups 1-6 (Surefil SDR® Flow [SDR]) composite resins). There is a significant difference when *p* < 0.05. Pairwise comparisons where there is a significant difference are shown in italics.

Contrast	Difference	Lower 95% CI	Upper 95% CI	p.value
G1 - G2	-2.48	-7.46	2.50	0.921
G1 - G3	-3.72	-8.70	1.26	0.689
G1 - G4	2.49	-2.49	7.47	0.920
G1 - G5	*24.04*	*19.06*	*29.02*	*<.0001*
G1 - G6	-0.20	-5.18	4.78	1.000
G2 - G3	-1.24	-6.22	3.74	0.996
G2 - G4	4.97	-0.01	9.94	0.395
G2 - G5	*26.52*	*21.54*	*31.50*	*<.0001*
G2 - G6	2.28	-2.70	7.26	0.944
G3 - G4	6.21	1.23	11.18	0.182
G3 - G5	*27.76*	*22.78*	*32.73*	*<.0001*
G3 - G6	3.52	-1.46	8.49	0.736
G4 - G5	*21.55*	*16.57*	*26.53*	*<.0001*
G4 - G6	-2.69	-7.67	2.29	0.893
G5 - G6	*-24.24*	*-29.22*	*-19.26*	*<.0001*

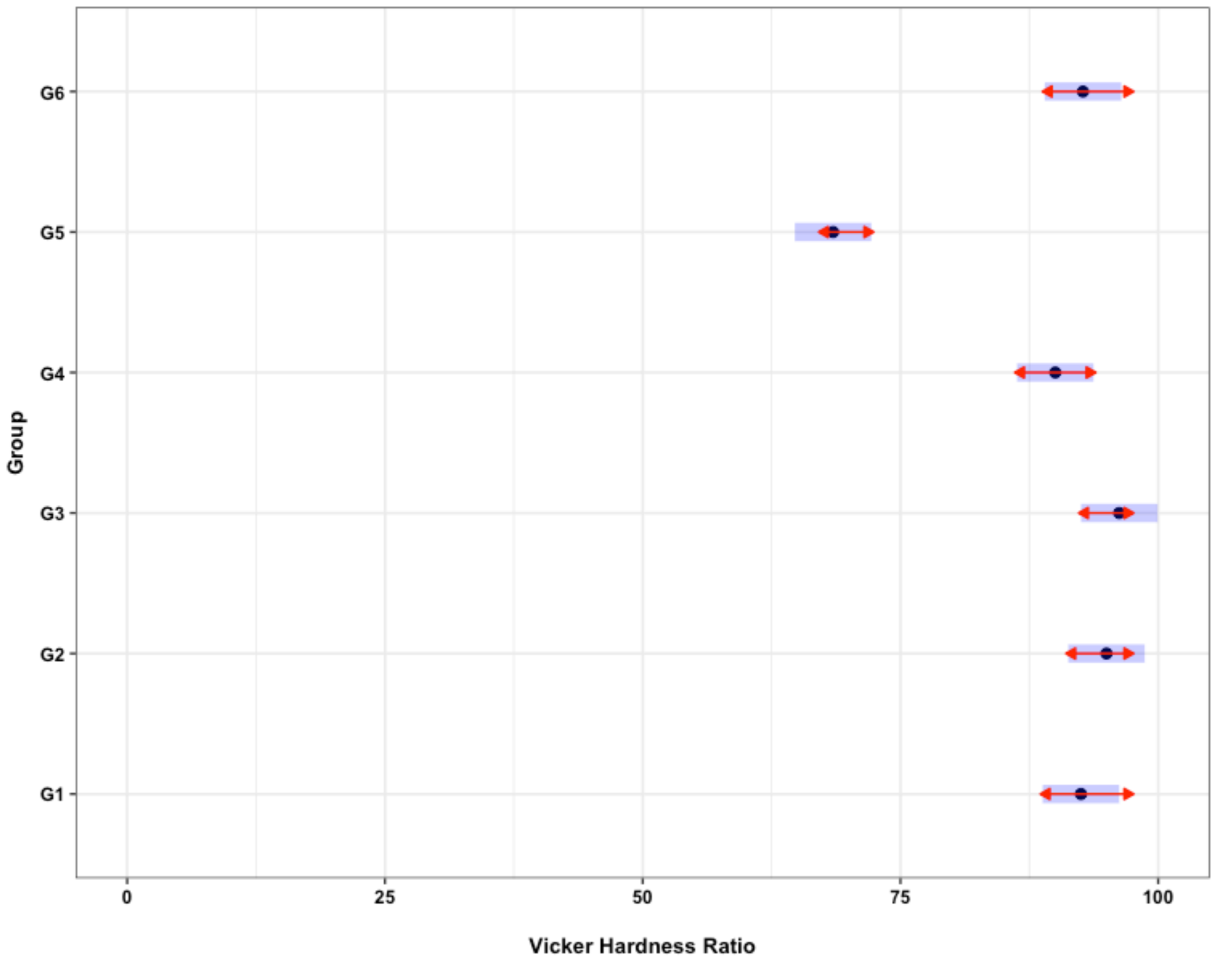

Figure 15: Plot of the Ratio of Vickers Hardness - Groups 1-6 (Surefil SDR® Flow [SDR]) composite resins). The blue bars are confidence intervals for the means, and the red arrows are for the comparisons among them. If an arrow from one group mean overlaps an arrow from another group, the difference is not significant.

Table 7: Pairwise Comparisons - Groups 7-12 (Tetric EvoCeram® [TEB]) composite resins). There is a significant difference when *p* < 0.05. Pairwise comparisons where these is a significant difference are shown in italics.

Contrast	Difference	Lower 95% CI	Upper 95% CI	p.value
G10 - G11	3.28	-2.52	9.09	0.873
G10 - G12	*-17.46*	*-23.26*	*-11.66*	*0.000*
G10 - G7	*-11.66*	*-17.46*	*-5.86*	*0.007*
G10 - G8	*-13.29*	*-19.09*	*-7.48*	*0.002*
G10 - G9	*-15.75*	*-21.55*	*-9.95*	*0.000*
G11 - G12	*-20.74*	*-26.55*	*-14.94*	*<.0001*
G11 - G7	*-14.94*	*-20.74*	*-9.14*	*0.001*
G11 - G8	*-16.57*	*-22.37*	*-10.77*	*0.000*
G11 - G9	*-19.03*	*-24.83*	*-13.23*	*<.0001*
G12 - G7	5.80	0.00	11.60	0.393
G12 - G8	4.17	-1.63	9.98	0.721
G12 - G9	1.71	-4.09	7.51	0.992
G7 - G8	-1.63	-7.43	4.17	0.993
G7 - G9	-4.09	-9.89	1.71	0.737
G8 - G9	-2.46	-8.26	3.34	0.958

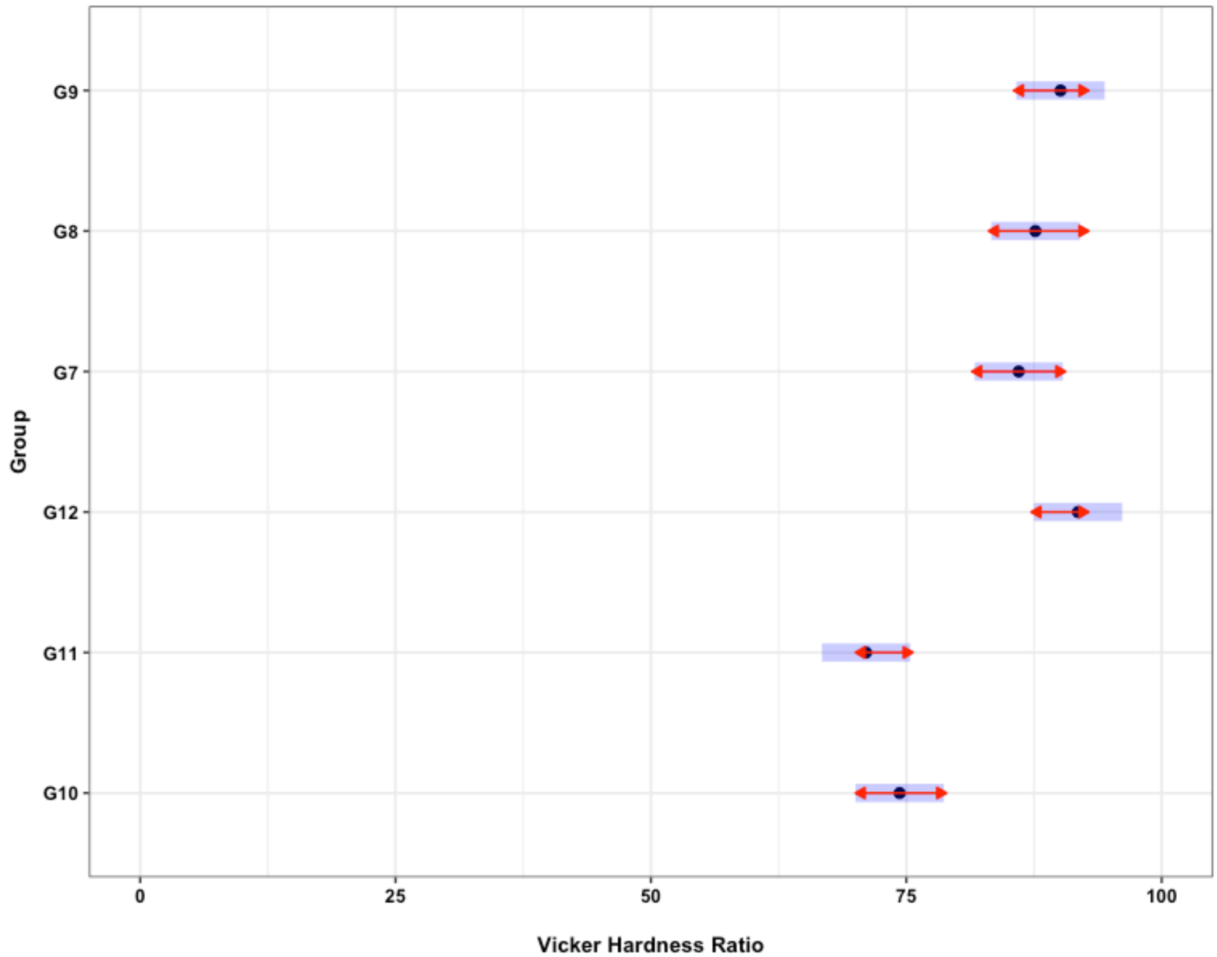

Figure 16: Plot of the Ratio of Vickers Hardness - Groups 7-12 (Tetric EvoCeram® [TEB]) composite resins). The blue bars are confidence intervals for the means, and the red arrows are for the comparisons among them. If an arrow from one group mean overlaps an arrow from another group, the difference is not significant.

Table 8: Pairwise Comparisons - Groups 13-18 (Filtek™ Supreme Ultra [FS]) composite resins). There is a significant difference when p < 0.05. Pairwise comparisons where there is a significant difference are shown in italics.

Contrast	Difference	Lower 95% CI	Upper 95% CI	p.value
G13 - G14	-3.10	-10.49	4.29	0.960
G13 - G15	-8.11	-15.51	-0.72	0.296
G13 - G16	*35.69*	*28.30*	*43.09*	*<.0001*
G13 - G17	*63.23*	*55.84*	*70.62*	*<.0001*
G13 - G18	*32.45*	*25.06*	*39.84*	*<.0001*
G14 - G15	-5.01	-12.40	2.38	0.767
G14 - G16	*38.80*	*31.40*	*46.19*	*<.0001*
G14 - G17	*66.33*	*58.94*	*73.73*	*<.0001*
G14 - G18	*35.55*	*28.16*	*42.94*	*<.0001*
G15 - G16	*43.81*	*36.42*	*51.20*	*<.0001*
G15 - G17	*71.35*	*63.95*	*78.74*	*<.0001*
G15 - G18	*40.56*	*33.17*	*47.95*	*<.0001*
G16 - G17	*27.54*	*20.15*	*34.93*	*<.0001*
G16 - G18	-3.25	-10.64	4.15	0.952
G17 - G18	*-30.79*	*-38.18*	*-23.39*	*<.0001*

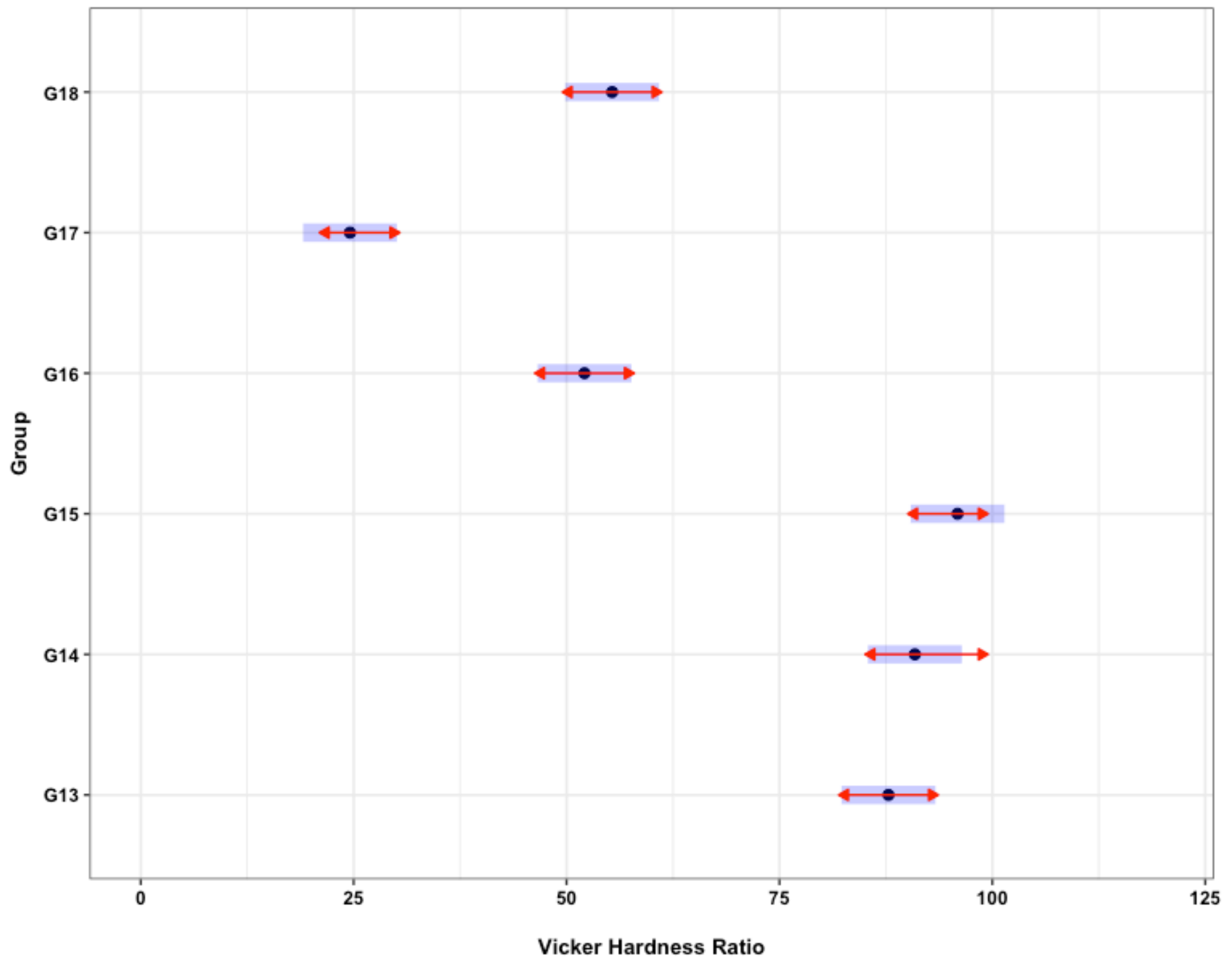

Figure 17: Plot of the Ratio of Vickers Hardness - Groups 13-18 (Filtek™ Supreme Ultra [FS]) composite resins). The blue bars are confidence intervals for the means, and the red arrows are for the comparisons among them. If an arrow from one group mean overlaps an arrow from another group, the difference is not significant.

CHAPTER 4

Discussion

In this study, the effect of curing light type and placement technique, on the microhardness of resin composite materials, was evaluated. The microhardness of composite resin materials was affected by both curing light type and placement technique used. Resin composite groups cured with LED CLU (extra-high power for 3 seconds) and placed using a bulk-fill technique showed a significant difference ($p<0.05$) among all groups. There were also significant differences in the depth of cure (hardness ratio) found for Filtek™ Supreme Ultra [FS] placed using bulk-fill technique regardless the curing light used. Tetric EvoCeram® [TEB] resin composite groups cured with LED CLU (standard-low power for 10 seconds) placed using a bulk-fill technique showed a significant difference. A summary of success or failure based on DOC hardness ratio is shown in Figure 18, where success is defined as a hardness ratio of 80% or greater at a depth of 4 mm.

Factors significantly affecting the hardness values of restorative materials include filler volume fraction, composition, resin type and degree of polymerization[47]. Variation in hardness is related to physical properties of composites, such as Young's modulus of elasticity and the viscosity of the un-cured material[47]. The type of resin matrix, i.e., the monomer(s) comprising the organic part of the composite, influences the viscosity. Bis-GMA is the most viscous monomer, and is also the least flexible, while UDMA and TEGD-MA are less viscous, and act as diluents[47-49]. Kelić et al. (2016) and Soygun et al. (2015) reported that flowable (low-viscosity) bulk-fill resin composites displayed lower surface microhardness values when compared to condensable (high-viscosity) bulk-fill resin composites and conventional nano-composites[47, 50]. In the present study, regardless of the light curing unit and insertion technique used, there was a difference in the surface hardness values of different materials, which can be explained by their different filler contents. The highest microhardness among all composite materials in this study belonged to Filtek™ Supreme Ultra [FS] composite groups, while the lowest surface microhardness was that measured for Surefil SDR® Flow [SDR] composite groups. The lower microhardness can be explained by the lower filler content, which is necessary for obtaining the reduced viscosity of a flowable dental composite.

Numerous studies have defined depth of cure based on hardness measurements performed on the top and bottom surface of a light-cured resin composite specimen, and scientific literature provides that an acceptable depth of cure is achieved when the hardness of the bottom layer is at least 80% of the hardness measured at the top surface[42, 43]. The depth of cure is influenced by many factors, such as the chemical structure of the monomers, filler composition and size, curing time and light intensity[51], in this study, curing time was provided according to manufacturer recommendations for each light intensity (type of curing light), and each group was evaluated independently, so chemical structure and filler compositions were constant parameters. However, achieving uniform and high monomer conversion to full depth of the resin composite with less clinical steps of applying resin at the site of interest (bulk-filling) is the main target for many dental practitioners. Authors have discussed application and curing of resin composite in successive increments of limited thickness as being time-consuming and as increasing the risk of contamination within the increments, which can adversely affect the mechanical and physical properties of the set material[12, 52, 53]. Also, they discussed the dental practitioner's preference to use time saving clinical steps to place resin composite restorations[13, 14, 53]. Moharam et al. (2017) proved that depth of cure microhardness ratio of resin composites is affected by insertion technique (multiple increments or single bulk-fill) and concluded that there was a decrease in the microhardness values on the bottom surfaces for all tested resin composite materials when a bulk insertion technique was used[53]. In the present study, regardless of the curing-light used, Filtek™ Supreme Ultra [FS], Tetric EvoCeram® [TEB] and Surefil SDR® Flow [SDR] composite resins placed as two increments of 2 mm showed greater depth of cure (hardness ratio) when compared with placement of the materials as a 4 mm single bulk layer.

Dentists may choose from different types of curing lights for the photo-polymerization of composites, such as quartz tungsten-halogen (QTH) or light emitting diode (LED) curing units. Light-curing units must deliver both sufficient energy and light at the correct wavelength, matching the wavelength of excitation of the photo-initiator, to produce an acceptably cured restoration[45]. Soygun et al. (2015) and Topcu, et al. (2010) concluded that resin composite specimens, polymerized via halogen lights, displayed higher microhardness than the specimens polymerized with LED light sources[50, 54]. The present study tested the influence of different light curing units on different types of resin composites. The results of this study were parallel to other studies, and confirm that the microhardness values of the specimens, which were polymerized with halogen light sources, were higher than those polymerized with LED CLU. It is possible that halogen lights are a better polymerization tool because halogen light sources generally have higher energy density and longer recommended application times when compared to LED light sources. Church et al. (2017) concluded that Filtek™ Supreme Ultra [FS] cured with a halogen light for 20 sec reached an acceptable depth of cure up to 3 mm [55]. In the present study, Filtek™ Supreme Ultra [FS] composite resin placed as a single bulk layer (4 mm), cured with LED standard power and Halogen curing units showed a depth of cure up to 3 mm. Therefore, it would not be recommended to use a bulk-fill technique with this type of conventional composite.

At present, LED CLUs are the preferred dental curing-light unit, and therefore most widely used. The manufacturers of most resin composites recommend that a 2 mm increment or 4 mm single bulk increment of composite should be irradiated for 10 to 40 seconds depending on the light intensity. The exposure times recommended by resin composite manufactures may be different from those recommended by the curing light manufactures[30]. To determine the exact time needed for curing a resin composite, curing time can be estimated using the formula of total energy concept:

$$\text{Resulting curing time} = \frac{\text{Required energy dose}}{\text{Light intensity}}$$

Total energy concept is the required dose for adequate curing, and depends on the type, shade and translucency of the composite[56, 57]. As a general rule, a dose of maximally 16,000 mW/cm^2 is required to adequately cure a single increment, although for some resin composites, the value may be less. For example, the manufacturer of Tetric EvoCeram® Bulk-Fill recommends an energy dose of 10,000 mW/cm^2, claiming the material can be light-cured to a depth of 4 mm using a light-curing time of 10 sec provided that the LED CLU power intensity is ≥1000 mW/cm^2. In the present study Tetric EvoCeram® [TEB] composite resin placed as one bulk layer of 4 mm and cured with LED standard power (1000 mW/cm) for 10 sec reached the acceptable 80% hardness ratio only to a depth of 3.2 mm. That confirms other studies by Soygun et al.

(2015) and Flury et al. (2012), which reported that the curing time using a standard LED CLU unit (≥1000 mW/cm^2), suggested by the manufacturer for curing to a 4 mm depth, was insufficient. These studies concluded that the curing time should be doubled[39, 50].

In general, curing light manufactures recommend irradiation times between 3 to 40 seconds depending on the combination of light intensity and wavelength range for a given light curing unit. Many dental clinicians aim to achieve a full depth of cure of the resin composite with a shorter exposure time, as this might increase productivity and lessen the amount of working time intraorally. Curing time is set depending on the irradiance level. Theoretically, the higher the irradiance level, the shorter the curing time needed. For the LED unit used in this study (Valo® LED curing unit with extra power - 3200 mW/cm^2), the manufacture recommends 3 sec irradiation per increment. This recommendation was not in agreement with the findings of the present study, which found that 3 sec irradiation time was insufficient to cure a 4 mm single bulk increment. However, a 3 sec irradiation time, as also recommended for 2 mm increments, was in agreement with the findings of the present study, where 3 sec was enough to reach a full depth of cure.

In a similar study, Al Qahtani (2015), concluded that photocuring a resin composite using a PAC light for five seconds (7328 mW/cm^2) resulted in the shallowest depth of cure when compared with halogen and LED curing lights.[45]. This study supports the idea that applying a short curing time using high light intensity can result in less than adequate depth of cure of resin composite materials. This might be explained by a possible change of some of the electromagnetic energy (light energy) into thermal energy during interaction with the material, with a subsequent reduction of the available energy left to complete polymer conversion. In addition, differences in resin composite composition can affect degree of conversion, as some of materials might be incapable of absorbing curing light energy efficiently enough for a short burst of high intensity light to work effectively.

Additionally, it is possible that the accuracy of radiometers used to determine light intensity can vary greatly from one device to another, which would result in errors when estimating proper curing times for a given light curing unit. Also, despite the desire to achieve a full depth of cure of resin composite with as short an exposure time as possible, many studies confirm that high intensity curing lights may play an important role in pulp temperature rise[36]. Therefore, they should be avoided to prevent any pulp damage.

Finally, as this study is characterized by bench testing with ideal scenarios in regards to curing light position and distance from the composite surface, one must assume that this is a "best case" situation. In clinical practice, these factors are much more difficult to control and could affect the outcome. For example, a procedure performed where light access is very difficult and limited would likely yield a practical level of polymer conversion not as good as that demonstrated in this study, and perhaps result in a premature failure of the restoration.

The limitations of this study include the fact that this is an in vitro study that will not precisely replicate in vivo conditions, or replace well-designed clinical studies. Also, the accuracy of readings is dependent on the accuracy of the equipment utilized, and could be different if performed in a different laboratory with different instrumentation.

	Halogen QHT LCU ($740\ mw/cm^2$) 40 seconds except for incremntal.t SDR 20 seconds	LED LCU ($1000\ mw/cm^2$) 10 seconds except for bulk.t SDR 25 seconds	LED LCU ($3200\ mw/cm^2$) 3 seconds
Surefil SDR® (SDR)			
Incremental technique	✓	✓	✓
Bulk technique	✓	✓	✗
Tetric Evoceram® (TEB)			
Incremental technique	✓	✓	✓
Bulk technique	✓	✗	✗
Filtek™supreme ultra(FS)			
Incremental technique	✓	✓	✓
Bulk technique	✗	✗	✗

Figure 18: A summary of success or failure based on DOC hardness ratio, where success is defined as a hardness ratio of 80% or greater at a depth of 4 mm.

CHAPTER 5

Conclusion

Within the limitations of this study, the following conclusions are made:

1- Microhardness ratio (Depth of cure) was influenced by the type of light source used.

2- The depth of cure level for the specimen groups, which were polymerized with a halogen light source, was superior when compared to values measured for specimens polymerized with a LED light source.

3- There were differences among the surface microhardness levels for different resin composite materials, which can be explained by their different filler content.

4- When an incremental insertion technique was used, a significantly higher depth of cure for all composite resin groups was found when comparing to bulk insertion.

5- Increasing the recommended increment thickness for the conventional resin composite (Filtek™ Supreme Ultra [FS]) cured with both LED and Halogen curing units, showed a depth of cure of only approximately 3 mm. Therefore, it would not be recommended to use a bulk-fill technique with this type of conventional composite.

6- Increasing the recommended increment thickness for the conventional resin composite decreased the depth of cure, but depth of cure generally remained constant for the bulk fill resin composites.

7- Materials did not always meet the manufacturer claims for depth of cure for given light intensity and irradiance time combinations, and there was a reasonable correlation between radiant energy (light intensity) and irradiance time.

8- The combination of high irradiance (3200 mW/cm^2) and short exposure time (3 seconds) for LED CLU extra power did not exceed the threshold value for bottom to top hardness ratio of 80% at 4 mm depth of cure claimed for bulk-fill composites when using a bulk-fill insertion technique.

9- Based on the findings of this study, a strong argument (recommendation) can be made that short exposure times with very high light intensities results in inadequate curing, and should be avoided in clinical practice.

All of these conclusions have clinical relevance, and should be considered in establishing guidelines for the clinician in order to obtain good clinical outcomes while using resin composite as a direct restorative material.

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Appendices

Appendix A: Raw Data for Groups 1-6:

				Vickers hardness number (VHN) - 10 Reading per sample											VH Ratio %
ID	Group			VHN1	VHN2	VHN3	VHN4	VHN5	VHN6	VHN7	VHN8	VHN9	VHN10		
1	G1:SDR® Composite	2-mm increments	LED-Low power	46.1	44.7	44	46.8	46.7	44.4	44.2	42.1	41.5	41.3		
2	G1:SDR® Composite	2-mm increments	LED-Low power	44.2	45.3	42.5	43.5	41.5	47.2	45.6	44.1	41.8	41.6		
3	G1:SDR® Composite	2-mm increments	LED-Low power	45	45.1	44.7	41.5	40.9	43.8	43.6	41.3	41	40.7		
4	G1:SDR® Composite	2-mm increments	LED-Low power	46.8	44.5	44.3	44.3	44	47.5	47.4	46	45.4	44.7		
5	G1:SDR® Composite	2-mm increments	LED-Low power	44.8	43.4	43.5	41.9	40.5	44.1	42.8	41.6	41.5	41.6		
Group 1 Avg				45.38	44.6	43.8	43.6	42.72	45.4	44.72	43.02	42.24	41.98		92.5077126
6	G2:SDR® Composite	2-mm increments	LED-High power	47	46.7	46.2	46.4	46.4	46.2	46.5	45.8	45.9	44.1		
7	G2:SDR® Composite	2-mm increments	LED-High power	47.1	45.5	45.2	45.9	46	47.3	46.8	46.1	45.7	45.6		
8	G2:SDR® Composite	2-mm increments	LED-High power	47.2	46.5	46.6	46.1	45.6	47.8	46.4	44.4	44.2	44.3		
9	G2:SDR® Composite	2-mm increments	LED-High power	49.2	47.5	47.1	47	46.8	49.1	48.9	48.2	46.7	45.6		
10	G2:SDR® Composite	2-mm increments	LED-High power	44.1	43.8	43.7	42.6	42.8	46	45.2	43.3	43.3	43.1		
Group 2 Avg				46.92	46	45.76	45.6	45.52	47.28	46.76	45.56	45.16	44.54		94.9275362
11	G3:SDR® Composite	2-mm increments	Halogen light	44.8	44.7	44.7	43.9	42.3	47.4	45.5	47.4	46.7	46.3		
12	G3:SDR® Composite	2-mm increments	Halogen light	45.1	44.6	44.8	43.5	42.5	46.9	46.4	42.7	41.6	40.9		
13	G3:SDR® Composite	2-mm increments	Halogen light	42.2	44.5	43.1	41.4	41.6	43.6	42.8	42.6	41.8	40.9		
14	G3:SDR® Composite	2-mm increments	Halogen light	45	43.1	43	42.6	42.1	47.4	46.7	44.6	43.6	42.5		
15	G3:SDR® Composite	2-mm increments	Halogen light	44.3	43.3	43	42.6	42.1	45.2	44	43.8	43	42.4		
Group 3 Avg				44.28	44.04	43.72	42.8	42.12	46.1	45.08	44.22	43.34	42.6		96.2059621
16	G4:SDR® Composite	4-mm increment	LED-Low power	51.7	48.1	47.1	51	46.5	42.5	43.9	45	42.1	43		
17	G4:SDR® Composite	4-mm increment	LED-Low power	45.4	48.1	46.8	57.1	46.9	42.3	43.3	45.1	44.7	43.6		
18	G4:SDR® Composite	4-mm increment	LED-Low power	48.8	47.9	46.9	45.3	45.3	43.8	43.9	43.2	43.4	42.9		
19	G4:SDR® Composite	4-mm increment	LED-Low power	49.1	47.5	47	47.2	46.5	45.7	45.6	46.2	43	44.9		
20	G4:SDR® Composite	4-mm increment	LED-Low power	46	44.2	46.4	45.8	45.7	45.9	45.2	43.3	43.7	42.1		
Group 4 Avg				48.2	47.16	46.84	49.28	46.18	44.04	44.38	44.56	43.38	43.3		89.8340249
21	G5:SDR® Composite	4-mm increment	LED-High power	63.5	63.9	56	55.4	55.2	54.3	54.6	52.2	47.5	46.1		
22	G5:SDR® Composite	4-mm increment	LED-High power	50.7	45.8	43.3	44.9	41.8	41.8	44.3	40.1	35.1	31.4		
23	G5:SDR® Composite	4-mm increment	LED-High power	52.1	50.3	49.4	48.2	42.1	38.4	38.9	37.1	34.9	33.9		
24	G5:SDR® Composite	4-mm increment	LED-High power	50.2	47.2	43.9	42.6	40.4	38.6	38.4	37.2	34.8	35.7		
25	G5:SDR® Composite	4-mm increment	LED-High power	45.8	42.2	44.7	42.6	40.2	38.9	37.1	35.9	33.1	32.8		
Group 5 Avg				52.46	49.88	47.46	46.74	43.94	42.4	42.66	40.5	37.08	35.98		68.585589
26	G6:SDR® Composite	4-mm increment	Halogen light	42.2	45.5	43.2	46.3	34.1	39.8	38.1	40	39.7	40.9		
27	G6:SDR® Composite	4-mm increment	Halogen light	43.4	43.4	44.8	43.9	46.8	42.2	44.9	45.4	42.7	38		
28	G6:SDR® Composite	4-mm increment	Halogen light	46.2	46	45.8	47.8	47.1	44.8	43.9	42.7	43	42.9		
29	G6:SDR® Composite	4-mm increment	Halogen light	43	42.8	42.1	43	43.3	43.2	43.2	41.7	42.5	41.8		
30	G6:SDR® Composite	4-mm increment	Halogen light	45.4	44.8	43.2	43.7	44	43.7	42.9	40.1	42.2	40.4		
Group 6 Avg				44.04	44.5	43.82	44.94	43.06	42.74	42.6	41.98	42.02	40.8		92.6430518

Appendix B: Raw Data for Groups 7-12:

				Vickers hardness number (VHN) - 10 Reading per sample											VH Ratio %
ID	Group			VHN1	VHN2	VHN3	VHN4	VHN5	VHN6	VHN7	VHN8	VHN9	VHN10		
31	G7:TEB® Composite	2-mm increments	LED-Low power	75.4	74.9	73.9	68.9	67.9	70.4	69	67.9	67.7	66.6		
32	G7:TEB® Composite	2-mm increments	LED-Low power	74.4	72.4	71.6	67.1	66.8	74	72.8	71	66.2	63.4		
33	G7:TEB® Composite	2-mm increments	LED-Low power	78.9	75.4	73.4	68.7	67.2	73.8	70.3	69.2	65.2	65		
34	G7:TEB® Composite	2-mm increments	LED-Low power	76.6	73.3	70.8	67.6	67.1	75.8	72.5	68	64.2	62.9		
35	G7:TEB® Composite	2-mm increments	LED-Low power	76.3	76.2	73.9	73.3	71.8	77.6	74.1	73	71.4	70.2		
Group 7 Avg				76.32	72.3	71.2	70	73.8	73.2	72.1	68	66.1	65.62		85.9800839
36	G8:TEB® Composite	2-mm increments	LED-High power	74.3	73.3	72	70.2	68.9	74.7	70.8	68	65.4	63.4		
37	G8:TEB® Composite	2-mm increments	LED-High power	75	72.9	70	66.9	65.1	71.5	69.2	68.2	63	62.1		
38	G8:TEB® Composite	2-mm increments	LED-High power	74.2	72.5	70.7	69.9	67.9	72.8	71.2	69.3	68.1	67.7	;	
39	G8:TEB® Composite	2-mm increments	LED-High power	73.4	72.3	71	68.3	65.2	74.4	73	71.8	70.4	68.4		
40	G8:TEB® Composite	2-mm increments	LED-High power	77.2	74.1	72.3	71.2	70	73.8	73.2	72.1	68	66.1		
Group 8 Avg				74.82	73.02	71.2	69.3	67.42	73.44	71.48	69.88	66.98	65.54		87.5968992
41	G9:TEB® Composite	2-mm increments	Halogen light	76.7	75.5	74.2	74	73.8	76.6	75.3	74.1	73.6	70.1		
42	G9:TEB® Composite	2-mm increments	Halogen light	76.3	75.5	74.8	74.1	74.2	76.2	75.7	73	69.8	67.1		
43	G9:TEB® Composite	2-mm increments	Halogen light	77.1	75.8	74.4	73.9	73.2	76.9	75.2	73	71.8	70.9		
44	G9:TEB® Composite	2-mm increments	Halogen light	76.9	75.1	74.1	73.3	73.1	77	75.9	74.2	72.2	70.1		
45	G9:TEB® Composite	2-mm increments	Halogen light	76.1	75.4	74.1	73.3	73.3	76.8	74.3	72.3	69.8	67		
Grpup 9 Avg				76.62	75.46	74.32	73.72	73.52	76.7	75.28	73.32	71.44	69.04		90.1070217
46	G10:TEB® Composite	4-mm increment	LED-Low power	89.6	88.7	98.7	96.6	84.9	90.4	90	78.8	71.6	70.3		
47	G10:TEB® Composite	4-mm increment	LED-Low power	81.2	72.3	62.1	68	67.8	65	61.1	62.3	60.1	59.7		
48	G10:TEB® Composite	4-mm increment	LED-Low power	66.6	68.1	67.9	63.4	67.2	62.6	60.7	59.9	56.8	55.4		
49	G10:TEB® Composite	4-mm increment	LED-Low power	83.5	82.3	73.5	62.9	62.7	62.7	62.1	60.7	55.1	55		
50	G10:TEB® Composite	4-mm increment	LED-Low power	80.6	79.3	71	64.6	56.1	59.7	62.4	59.5	59.7	57		
Group 10 Avg				80.3	78.14	74.64	71.1	67.74	68.08	67.26	64.24	60.66	59.48		74.0722291
51	G11:TEB® Composite	4-mm increment	LED-High power	73.5	69.8	68.5	68.2	69.2	66.5	64.5	60	58	51.1		
52	G11:TEB® Composite	4-mm increment	LED-High power	71.2	68.7	66.3	65.2	63.5	60.6	56.2	56	53.3	52.9		
53	G11:TEB® Composite	4-mm increment	LED-High power	76.3	77.3	77.3	74.1	66	61.2	58	56.1	55.3	49.9		
54	G11:TEB® Composite	4-mm increment	LED-High power	71.3	68.6	64.4	61.1	60	59.4	57.5	56	55.4	52.8		
55	G11:TEB® Composite	4-mm increment	LED-High power	73	69.8	66.1	65.1	63.3	60.1	57.9	58.7	55.1	52.6		
Group 11 Avg				73.06	70.84	68.52	66.74	64.4	61.56	58.82	57.36	55.42	51.86		70.9827539
56	G12:TEB® Composite	4-mm increment	Halogen light	75.3	67.2	66.8	66.3	67.2	66.7	67.5	66.8	66.6	67.7		
57	G12:TEB® Composite	4-mm increment	Halogen light	75	68.7	67.4	70.8	68.7	67.1	67	67.8	64.3	63.9		
58	G12:TEB® Composite	4-mm increment	Halogen light	71.3	70.5	69.9	66.4	65.1	65.4	64.9	66.5	66.1	64.4		
59	G12:TEB® Composite	4-mm increment	Halogen light	68.4	69.4	70.1	64.1	67	63.5	65.5	65.2	65.6	68.8		
60	G12:TEB® Composite	4-mm increment	Halogen light	70.4	70.5	70	69.3	68.1	66.4	67.1	66.7	66.9	65.5		
Group 12 Avg				72.08	69.26	68.84	67.38	67.22	65.82	66.4	66.6	65.9	66.06		91.6481687

Appendix C: Raw Data for Groups 13-18:

				Vickers hardness number (VHN) - 10 Reading per sample											VH Ratio %
ID	Group			VHN1	VHN2	VHN3	VHN4	VHN5	VHN6	VHN7	VHN8	VHN9	VHN10		
61	G13:FS™ Composite	2-mm increments	LED-Low power	90.5	84.8	86.1	83.2	91.3	93.3	86.6	83.5	80.1	70.5		
62	G13:FS™ Composite	2-mm increments	LED-Low power	98.5	97.1	96.6	93.1	93.9	97.1	96.3	95.4	95.2	92.1		
63	G13:FS™ Composite	2-mm increments	LED-Low power	96.8	94.8	93.9	93.6	93	96.6	93.3	93	92.6	91		
64	G13:FS™ Composite	2-mm increments	LED-Low power	96.5	94.9	92	92	90.3	95.1	93.2	92.1	89.8	85.8		
65	G13:FS™ Composite	2-mm increments	LED-Low power	99.3	96	94.8	93.3	92.9	96.2	93.4	91.3	87.1	84.1		
Grpup 13 Avg				96.32	93.52	92.68	91.04	92.28	95.66	92.56	91.06	88.96	84.7		87.9360465
66	G14:FS™ Composite	2-mm increments	LED-High power	100	99.7	99.2	98.7	98.2	100.5	99.2	97.7	95.7	92.3		
67	G14:FS™ Composite	2-mm increments	LED-High power	102	101.2	99.5	97.2	97	99.8	96.5	94.5	92.4	89.9		
68	G14:FS™ Composite	2-mm increments	LED-High power	99.3	97.6	96.3	95.7	94.5	99.5	98.1	96.2	94.6	92.3		
69	G14:FS™ Composite	2-mm increments	LED-High power	101.2	98.9	96.8	94.5	93.5	98.4	97.5	96.2	94.6	91.8		
70	G14:FS™ Composite	2-mm increments	LED-High power	99.2	98.7	97.8	96.5	95	103.5	99.3	97.9	95.4	89.7		
Group 14 Avg				100.34	99.22	97.92	96.52	95.64	100.34	98.12	96.5	94.54	91.2		90.8909707
71	G15:FS™ Composite	2-mm increments	Halogen light	98.6	97.4	96.3	96.2	96	98.5	97.1	96.5	95.9	95.2		
72	G15:FS™ Composite	2-mm increments	Halogen light	99.2	98.9	96.4	96.9	96.4	99.1	98.4	96	95.7	95.1		
73	G15:FS™ Composite	2-mm increments	Halogen light	96.8	96.1	96	95.1	97.7	99.5	97	95.9	95.1	94.9		
74	G15:FS™ Composite	2-mm increments	Halogen light	99.8	98.1	97.3	96.7	96.5	97.7	98	95.2	94.9	94.8		
75	G15:FS™ Composite	2-mm increments	Halogen light	98.9	97.9	97.3	96.3	97	97.1	96.6	96.8	94.1	93.1		
Group 15 Avg				98.66	97.68	96.66	96.24	96.72	98.38	97.42	96.08	95.14	94.62		95.9051287
76	G16:FS™ Composite	4-mm increment	LED-Low power	98.9	97.4	96.6	96.3	95.7	84	80	75.8	60	45		
77	G16:FS™ Composite	4-mm increment	LED-Low power	97.7	96.6	95.1	96.2	95.1	88.4	81.5	76.6	71.9	67.3		
78	G16:FS™ Composite	4-mm increment	LED-Low power	98.7	97.1	96.6	96.3	94.5	89	82.1	75.9	63.7	47.9		
79	G16:FS™ Composite	4-mm increment	LED-Low power	98.1	97.9	98.8	96.2	94.8	87.5	80.6	73.2	61.5	40.7		
80	G16:FS™ Composite	4-mm increment	LED-Low power	98.5	97.7	98.6	96.2	94	88.2	80.9	77.7	68.5	55.3		
Group 16 Avg				98.38	97.34	97.14	96.24	94.82	87.42	81.02	75.84	65.12	51.24		52.0837569
81	G17:FS™ Composite	4-mm increment	LED-High power	91.5	94.8	89.3	87.9	83.9	78.9	74.5	64.3	50.1	28.8		
82	G17:FS™ Composite	4-mm increment	LED-High power	91	93	88.1	86.8	84.9	75.3	66	48.2	37.4	19.7		
83	G17:FS™ Composite	4-mm increment	LED-High power	93.4	91.1	87.4	87.2	83.2	76.3	65.2	46.5	33.4	20.1		
84	G17:FS™ Composite	4-mm increment	LED-High power	92.4	93.1	87.1	86.2	82.1	75.2	67.5	50.5	35.6	18.3		
85	G17:FS™ Composite	4-mm increment	LED-High power	94	93.4	89.6	86.4	87.1	76.5	67.9	54.2	35.2	26.7		
Group 17 Avg				92.46	93.08	88.3	86.9	84.24	76.44	68.22	52.74	38.34	22.72		24.5727882
86	G18:FS™ Composite	4-mm increment	Halogen light	99.6	98.2	96.8	95.6	92.7	87.2	84.5	81.4	73	55.6		
87	G18:FS™ Composite	4-mm increment	Halogen light	98.1	97.6	96.5	95.7	93.4	89.6	88.7	80.2	75	60.6		
88	G18:FS™ Composite	4-mm increment	Halogen light	99.2	97.3	95.4	95.1	93.6	89.7	86.3	79.9	70.3	49.1		
89	G18:FS™ Composite	4-mm increment	Halogen light	99.8	97.7	96.8	95.1	94.2	88.7	86.1	79	70.5	56.2		
90	G18:FS™ Composite	4-mm increment	Halogen light	99.3	97.4	97.4	95.4	92.6	88.2	85.7	76	69.5	53		
Group 18 Avg				99.2	97.64	96.58	95.38	93.3	88.68	86.26	79.3	71.66	54.9		55.3427419